Application

for

United States Patent

To all whom it may concern:

Be it known that James S. Schutzbach has invented certain new and useful improvements in

METHOD AND SYSTEM FOR ANALYZING THE EFFECT OF INFLOW AND INFILTRATION ON A SEWER SYSTEM

of which the following is a full, clear and exact description:

METHOD AND SYSTEM FOR ANALYZING THE EFFECT OF INFLOW AND INFILTRATION ON A SEWER SYSTEM

FIELD OF THE INVENTION

5   The present invention relates generally sewage flow monitoring and analysis systems. More particularly, the present invention relates to a method and system of analyzing and/or predicting the effect of the inflow and/or infiltration of precipitation on a sewer system.

BACKGROUND OF THE INVENTION

10   Tools for the accurate measurement of flow in a sewer network are an important resource for managers, mechanics, engineers, and regulators of municipal and industrial sewer networks. Accurate measurements of flow, and an understanding of what flow is expected to occur during a precipitation event, can

15   help determine – and to predict – when network problems such as overflows, leaks, breaks, clogs, and other blockages and overflows may occur. They can also help system engineers and designers understand when additional capacity must be built into the system, as well as to help them better manage a network with its existing capacity.

20   Sewer network managers have attempted to analyze and predict what effect a rain event may have on a sewer network, but the prior attempts have been unsatisfactory because they do not provide for reliable, real-time prediction while the

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rain event occurs, but rather they involve the measurement of a rain event after it is

completed and the comparison of the measured event to known data from previous

similar events. In addition, the prior attempts to predict rain inflow and infiltration

on a sewer network involved significant, detailed modeling efforts, using data

5   relating to the design of the sewer network and/or network discharge sources. Such

modeling exercises are time-consuming and costly, and the accuracy of the modeling

results depends on how closely modeling conditions to match the conditions under

which the modeling was developed.

Accordingly, it is desirable to provide an improved method of, and system

10   for, analyzing and/or predicting the effect of inflow and/or infiltration on a sewer

network. The present invention is directed to such a system and method.

SUMMARY OF THE INVENTION

It is therefore a feature and advantage of the present invention to provide an

15   improved method of analyzing and/or predicting the effect of inflow and/or

infiltration on a sewer network. It is also a feature and advantage of the present

invention to provide an improved system for analyzing and/or predicting the effect of

inflow and/or infiltration on a sewer network.

In accordance with a preferred embodiment of the present invention, a

20   method of determining the effect of precipitation on flow within a sewer network

includes the steps of collecting, at a first location, data representative of a measured

rain quantity over a first time interval having a duration that is less than a twenty-

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four-hour period; maintaining, in a memory, data representative of a modeled rain response at a second location over a second time interval, the second time interval having a duration that is longer than the duration of the first time interval; calculating, in real time, a scaled rain response, the scaled rain response comprising a

5   function of the modeled rain response and the measured rain quantity; and reporting, in real time, the scaled rain response.

Optionally, the second location is a location within a sewer network, and the calculating of the rain response requires no additional data relating to either the sewer network or any substance flowing within the sewer network. Also optionally,

10   each modeled rain response is indicative of an anticipated increase in flow at the second location over the second time interval. The modeled rain response may be capable of graphical representation as a curve on a graph where a y-axis represents at least one of inflow and infiltration and an x-axis represents time. Also, the duration of the first time interval is preferably shorter than a duration of a corresponding

15   precipitation event.

Optionally, the method includes the additional step of identifying a cumulative scaled rain response that corresponds to a sum of a plurality of scaled rain responses over a plurality of time intervals. The method may also include the additional steps of measuring, using a flow meter at the second location, data

20   representative of a measured flow; subtracting a baseline flow from the measured flow to result in an adjusted flow; and comparing, using a processor, the adjusted flow to the scaled rain response to determine whether the adjusted flow substantially

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corresponds to the scaled rain response. The baseline flow preferably represents expected flow during a non-precipitation event. The comparing is preferably done using a goodness of fit test. If the comparing step determines that the adjusted flow and the scaled rain response do not substantially correspond, an alert may be

5   reported.

In accordance with an alternate embodiment of the present invention, a method of predicting the effect of precipitation on flow within a sewer network includes the steps of collecting data representative of a first measured rain quantity over a first time interval at a first location; creating, using a processor, multiple

10   possible rain responses, wherein each possible rain response represents a possible flow volume distribution at a second location over a second time interval, the second time interval being longer than the first time interval; measuring, using a flow monitor, a measured flow volume distribution at the second location over the second time interval; comparing, using the processor, the possible rain responses to the

15   measured flow volume distribution; selecting, using the processor, a modeled rain response that is the possible rain response that most closely corresponds to the measured flow volume distribution; and storing the modeled rain response, the first measured rain quantity, and the first time interval in a memory.

Optionally, the method also includes the steps of collecting data

20   representative of a second measured rain quantity over a third time interval at the first location; calculating, in real time by a processor, a scaled rain response

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comprising a function of the modeled rain response and the second measured rain quantity; and reporting, in real time, the scaled rain response.

Also optionally, the second location is a location within a sewer network, and the calculating of the rain response requires no additional data relating to either the

5   sewer network or any substance flowing within the sewer network. Further, the selecting step may include a goodness of fit test on the measured flow volume distribution and the plurality of possible rain responses. Preferably, the modeled rain response is capable of graphical representation as a curve on a graph where a y-axis represents at least one of inflow and infiltration and an x-axis represents time. Also

10   preferably, the first time interval has a duration that is shorter than a duration of a corresponding precipitation event.

As an additional option, the method may include the additional steps of measuring, using a flow meter at the second location, data representative of a measured flow; subtracting a baseline flow from the measured flow to result in an

15   adjusted flow, the baseline flow corresponding to a non-precipitation event; and comparing, using a processor, the adjusted flow to the scaled rain response to determine whether the adjusted flow substantially corresponds to the scaled rain response. With this option, if the comparing step determines that the adjusted flow and the selected rain response do not substantially correspond, an alert may be

20   reported.

In accordance with an additional alternate embodiment, a sewer network flow analysis system includes a processor, a memory in communication with the

processor, and a rain gauge in communication with the processor. The processor is programmed to accept, from the rain gauge, data representative of a measured rain quantity over a first time interval that is less than a twenty-four-hour period. The memory maintains data representative of a modeled rain response at a location in a

5   sewer network over a second time interval having a duration that is longer than the duration of the first time interval. The processor is further programmed to calculate, in real time, a scaled rain response comprising a function of the modeled rain response and the measured rain quantity. In addition, the processor is also programmed to report, in real time, the scaled rain response.

10   There have thus been outlined the more important features of the invention in order that the detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated. There are, of course, additional features of the invention that will be described below and which will form at least part of the subject matter of the claims appended hereto.

15   In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be

20   understood that the phraseology and terminology employed herein, as well as the abstract included below, are for the purpose of description and should not be regarded as limiting in any way.

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As such, those skilled in the art will appreciate that the concept and

objectives, upon which this disclosure is based, may be readily utilized as a basis for

the design of other structures, methods and systems for carrying out the several

purposes of the present invention.

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BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 illustrates an exemplary sewer network experiencing inflow and

infiltration during a precipitation event.

FIG. 2 is an internal diagram of an exemplary computing device having a

10   processor and a memory.

FIG. 3 is a flowchart that illustrates the steps by which the present invention

may learn the effects of inflow and infiltration on a sewer network.

FIG. 4 is a flowchart that illustrates the steps by which the present invention

may anticipate the effects of a precipitation event on a sewer network.

15   FIG. 5 illustrates exemplary rain responses to a measured rain event.

FIG. 6 illustrates an exemplary accumulation of rain responses in accordance

with the present invention.

FIG. 7 illustrates an example of a total computed rain response.

FIG. 8 illustrates the comparison of an exemplary computed rain response

20   with an exemplary actual rain response.

FIG. 9 illustrates the development of a scaled rain response as a function of a

quantity of rain and a modeled rain response.

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DETAILED DESCRIPTION OF PREFERRED

EMBODIMENTS OF THE INVENTION

A preferred embodiment of the present invention provides an improved

5   method of analyzing and/or predicting the effects of inflow and infiltration on a

sewer network. Once determined, the information and knowledge of these effects

can be used to help sewer network managers detect discrepancies and/or unexpected

network conditions, identify flow monitor malfunctions, and plan for system

expansions.

10   FIG. 1 provides an illustration of the general concepts of rain-dependent

inflow and infiltration on an exemplary sewer network. Referring to FIG. 1, a sewer

network 2 contains a wastewater substance 4 that flows within the sewer network.

Various flow monitors 6 and 8 are stationed at various points throughout the sewer

network. Each flow monitor measures the velocity and/or volume and/or other

15   parameters relating to the flow at a monitoring point within the sewer network. The

monitors may be of any standard design or type that is capable of measuring flow

velocity, either directly or indirectly by performing calculations on one or more

measured parameters. Such a monitor is described in, for example, U.S. Patent No.

5,198,989, to Petroff; U.S. Patent No. 4,630,474, to Petroff; and U.S. Patent No.

20   4,397,191, to Forden.

One or more rain gauges such as 10 and 12 are also stationed at various

points above the sewer network to collect precipitation data such as rain and/or snow

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volume, precipitation event duration, and precipitation event intensities. During a precipitation event **14** such as a period of rain, rain may enter the system **2** through direct discharge points **16**, such as a storm drain or other opening into the sewer network, where the rain becomes inflow **18** into the sewer network. Alternatively,

5   the precipitation may seep into the sewer network as infiltration **20** through soil and/or other earthen materials, as well as through cracks and other openings within the sewer network above and/or under the soil. Typically, inflow **18** occurs during the rain event and for a brief period of time after the rain event as storm water runoff flows into a storm drain. Infiltration **20**, however, typically occurs for a longer

10   period of time as precipitation migrates through soils, rocks, and other materials before reaching the sewer network. For example, FIG. 1 illustrates that infiltration **22** is occurring even though the precipitation event **14** has passed beyond the point of the infiltration **22**.

The amount and the locations of the monitors, rain gauges, precipitation events, and flow volumes illustrated in FIG. 1 are merely intended as illustrative of

15   an example of a sewer network that is equipped with the present invention. Any number and location of monitors and rain gauges may be used in connection with any precipitation event.

The present invention employs a computer system using a computer

20   processor and a memory. An internal diagram of such a system is illustrated in FIG. 2. At a minimum, the system includes one or more memory devices **30** and **32** and a processor **34**. The computer also includes a communications port **31** that serves to

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receive data from the flow monitors and rain gauges. Each rain gauge and each flow

monitor is in communication with the computer system, whether by direct wiring or

through a remote communication medium, such as dial-in lines, a wireless

transceiver, and/or an Internet connection. Optionally, the computer system may be

5   integral with one or more of the rain gauges or flow monitors. The data collected by

the rain gauges and flow monitors is delivered to the processor and memory for

storage, analysis, and use.

The processor uses the data collected by the flow meters and rain gauges to

learn the sewer network's typical response to a precipitation event and to predict the

10   effects of future precipitation events, in real time as they occur. FIG. 3 illustrates the

steps that such a system may perform to learn the rain response of a sewer network to

a precipitation event. These steps include the collection 50 of rain quantity data over

one or more discrete periods of time. The time periods are relatively brief, in each

case less than a twenty-four hour period, and preferably in smaller intervals such as

15   five-minute intervals, ten-minute intervals, fifteen-minute intervals, thirty-minute

intervals, or any other interval that is less than twenty-four hours. The smaller the

interval, the better that the system may anticipate rain responses, as the system will

have data related to smaller time increments.

Using the processor, the system then generates 52 one or more possible rain

20   responses representing the increase in flow that the sewer network will experience

over a period of time in response to the rain. Preferably the system generates a large

number of rain responses, such as one hundred, two hundred, or more in order to

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provide multiple possibilities of rain response prediction. Using a display, each rain response may be optionally depicted as a hydrograph showing an immediate response to the inflow and/or infiltration of the rain, with an abrupt or gradual decrease in flow as the system returns to normal conditions after the rain event.

5   The system also collects **54** data representative of actual flow volume and compares **56** the possible rain responses identified in step **52** to the actual flow volume. Using a goodness of fit test to compare the rain responses to measured flow volume, the system selects **58**, as the modeled rain response, the possible rain response having the best fit with the measured flow volume. The modeled rain

10   response is stored **60** in a database, along with its corresponding rain quantity and rain time interval. The steps illustrated in FIG. 3 are preferably repeated over multiple time intervals, as well as during multiple rain events, in order to provide a broadly populated database of possible rain responses corresponding to varying rain intensities and rain time intervals. In addition, the process may be repeated for

15   different flow monitors and rain gauges to provide data relating to various locations throughout the sewer network.

Optionally and preferably, the steps illustrated in FIG. 3 are periodically repeated over various time periods, such as weekly, monthly, and/or annually, to provide periodic, automatic calibration of the modeled rain response. In addition, as

20   such time periods pass, the database of possible rain responses become more populated, thus providing more accurate determination of the modeled rain response over time.

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FIG. 4 illustrates the steps that the present invention may follow to predict a rain response using the data that was collected and stored as shown in FIG. 3. Referring to FIG. 4, the system maintains **70** the modeled rain responses in a memory, and it receives **72** actual rain quantity data over a time interval from one or more flow monitors. The system then calculates **74** a scaled rain response as a function of the modeled rain response and the rain quantity. The function is preferably done by multiplication of the modeled rain response, which corresponds to a known rain quantity, by the factor by which the actual rain quantity exceeds the known rain quantity. A graphic illustration of an exemplary multiplication of a modeled rain response by a rain quantity in a time interval is illustrated in FIG. 9. Returning to FIG. 4, the scaled rain response is then reported **76**. This report may be in the form of a direct communication to a user via a display, electronic mail, sonic alert, printout, or other communications medium, or the reporting may be simply the delivery of the selected rain response data to a processor, a storage medium such as a computer memory, or a transmission medium such as an analog or digital signal for further handling, use, or storage. Steps 72-74 may be repeated, and the scaled rain responses summed, to yield a cumulative rain response (as described below in the discussion relating to FIG. 6).

The scaled or cumulative rain response may be used to determine whether sewer network problems, such as pipe leaks, overflows, or monitor errors are occurring by comparing the selected rain response to actual measured data. These steps, which also are illustrated in FIG. 4, include the steps of measuring **78** actual

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sewer flow, using a flow monitor, and subtracting **80** a baseline flow from the

measured sewer flow. The baseline flow represents the flow that normally occurs at

the flow monitor's location during non-precipitation conditions, and the subtraction

of baseline flow from measured sewer flow results in an adjusted flow that is

5   representative of the inflow and infiltration on the system from the rain event. The

system then compares **82** the adjusted flow to the scaled or cumulative rain response

to determine whether the adjusted flow substantially corresponds to the scaled or

cumulative rain response. If there is a substantial difference between the adjusted

flow and the selected rain response, then the system may alert **86** a user or another

10   system or device of a potential problem in the sewer network. The alert may be, for

example, a direct communication to a user via a display, electronic mail, sonic alert,

printout, or other communications medium, or the alert may be as simple as the

delivery of the correspondence data to a processor, a storage medium such as a

computer memory, or a transmission medium such as an analog or digital signal for

15   further handling, use, or storage.

The determination of scaled rain response may also be used to calculate or

predict net flow between two points in a sewer network. For example, if flow is

measured at an upstream point in the network, the system can predict the flow at a

downstream location using the scaled determination of inflow and infiltration. The

20   prediction may also be configured to account for the amount of time that it takes a

unit of flow to travel from the upstream location to the downstream location.

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FIGs. 5-8 provide a graphic illustration of the determination of rain response

following the steps of FIG. 2. Referring to FIG. 5, a sewer network's response to an

interval of rain may be illustrated as a hydrograph. A hydrograph is a graph showing

a property of a fluid, in this case sewer flow volume, over a period of time. In FIG.

5, the fluid property is shown on a y-axis and the time is shown on the x-axis. The

graph typically follows the shape of a parabola, sine wave, or other shape having a

rising portion, a crest or a peak, and a hyperbola or recession curve. Examples of

two hydrographs of rain responses over a period of time, such as twenty-four hours,

are illustrated in FIG. 5. Different sewer networks, different locations within a sewer

network, and even different rain events having different intensities and/or time

intervals will yield different rain responses, as illustrated by the two different

hydrographs in FIG. 5. A similar type of graph, a hyetograph, would illustrate a

quantity of rain over a period of time.

As noted above, each interval of rain represents only a portion of an overall

rain event, such as a period during which an inch of rain is received, or a period

within which 1/100th of an inch of rain is received, or any interval of a total rain

event. The overall rain response is determined by accumulating a plurality of

hydrographs as illustrated by example in FIG. 6. For example, the first rain tip may

yield a rain response identified as curve 100, while the second rain tip, which

occurred after the rain tip, would yield a peak that is later in time. The response

curves for the second tip 110, the third tip 120, and any number of additional tips are

added to the first rain response curve to yield a total rain response. This continues

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for as many rain increments as desired to yield the overall rain response of the

system. After several overall rain responses are computed, an example of which is

illustrated in FIG. 7 as **170**, FIG. 8 illustrates that the computed overall rain response

170 may be compared to the actual rain response **180** to find the computed rain

5   response that has the best fit with the actual rain response. This comparison is done

using a goodness of fit test, such as the such as the Kolmogorov-Smirnov test, the

Pearson's chi-square test, or any other such test.

The many features and advantages of the invention are apparent from the

detailed specification, and thus, it is intended by the appended claims to cover all

10   such features and advantages of the invention which fall within the true spirit and

scope of the invention. Further, since numerous modifications and variations will

readily occur to those skilled in the art, it is not desired to limit the invention to the

exact construction and operation illustrated and described, and accordingly, all

suitable modifications and equivalents may be resorted to, all of which may fall

15   within the scope of the invention.

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